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Quality Engineering of Scrim-Reinforced Balloons

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XXVII. Quality Engineering of Scrim-Reinforced Balloons

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Abstract

The scrim-reinforced Mylar balloon is a highly reliable carrier for heavy, expensive, scientific payloads but has been prohibitively expensive for general use. A 30 percent cost reduction has resulted from an 18-month program evaluating new films, fibers, and adhesives, refined lamination techniques, and balloon design simplification in combination with streamlined production procedures.

The successful flight test of a nonwoven scrim balloon, the development of a novel nonwoven scrim loom, as well as scheduled tests for balloon recovery and reuse, promise to further reduce the cost differential between supported and unsupported film balloons.

1. INTRODUCTION

Ever since its introduction in 1945, the polyethylene balloon has been the workhorse of the balloon field. It has lifted scientific payloads of seemingly end-less variety, been launched from the arctic to the tropics, in fair weather and foul, and has carried man practically to the top of the atmosphere for physiologic and environmental research. Although generally satisfactory, it has occasionally failed during ascent, especially when structural demands on the balloon vehicle have been too great.

During the fall of 1958, the National Science Foundation, Office of Naval Research, and Johns Hopkins University were engaged in a joint field test expedition in which two men were to fly a polyethylene balloon for astronomical observations. Shortly before scheduled take-off, failure of the balloon while it was still on the ground aborted the entire expedition. This experience provided dramatic motivation for developing a stronger, more reliable, balloon material whose safety factors were greater than obtainable with polyethylene. Further emphasis came from the stringencies of heavier payloads, an occasional need to launch under somewhat less than ideal conditions, and the advisability of greater protection of the costly investments in test equipment and flight operations.

Accordingly, a contract was initiated by ONR, under the terms of which the G. T. Schjeldahl Company was to produce a high-reliability balloon film from knowledge of the best of the current technology in plastic films and fibers. The contract resulted in a study of candidate materials and selection of the best available film-fabric combinations; several balloon flights clearly indicated that a strong, light material was feasible.

Tests were made during flights of the Stratoscope II telescope which, together with the flight instrumentation and ballast, made up a balloon payload of some 10,000 pounds. The first flight of this huge system took place at Hope, Arkansas, on 6 March 1962. Although not fully meeting the sponsor's requirements, the results of this flight were encouraging. The ensuing series of balloon flights has been beset by problems, as has any other complex pioneering system, but none of the scrim balloons has suffered catastrophic failure during ascent.

The Air Force Cambridge Research Laboratories first became interested in the scrim balloon during Project Stargazer. The mission required lifting a two-man, 4,000-pound gondola to an altitude of 80,000 feet for a one-day period but when flight tests with the reinforced polyethylene balloon designed for the task scored only 50 percent, a scrim-reinforced balloon was given a series of test flights. Several deficiencies previously unsuspected in such balloons were uncovered. These were corrected in cooperation with the G. T. Schjeldahl Company; and on 13 December 1962, under the overall direction of Major Thomas B. Spalding of AFCRL, a successful flight was made by Mr. William White and Major Joseph Kittinger, accompanied by a 5,200-pound payload of scientific instrumentation.

The story has been somewhat the same with other programs involving the flight of heavy payloads. Even though the cost has ranged from five to ten times higher when scrim-reinforced Mylar balloons have been substituted for their polyethylene counterparts, the change to the more reliable scrim balloon has been justified by the results.

2. DEVELOPMENTAL PROGRAM

Early in 1963, AFCRL initiated a program to lower the cost of scrim-reinforced balloons by 30 percent within the year. Four areas were delineated for investigation. It appeared certain that basic balloon fabrics could be had for less money; scrim balloon designs could be both simplified and improved; production could be accelerated without sacrificing balloon quality; and launchings could be simplified to eliminate the need for a two-balloon launch system. The program was later expanded to include the recovery and re-use of scrim balloons.

2.1 Materials

The currently satisfactory Mylar—Dacron scrim is a clearly superior balloon fabric consisting of a plastic, gas-barrier film bonded to a network of reinforcing fibers by a thermoplastic adhesive. To find ways of reducing the cost of the basic balloon material without seriously compromising its good properties, a large number of films and lightweight fibers were obtained and tested. The more important characteristics of the better samples of scrims and films are summarized in Tables 1 and 2. Among the laminations tested were Dacron combined with polypropylene fibers, and polypropylene combined with Mylar film. Of the two adhesives used, the proprietary product of the Schjeldahl Company proved more suitable than the commercially available adhesive. Tests of nine different combinations of films, fibers, and adhesives gave the results summarized in Table 3. The balloon laminate used as the criterion for all the others was GT-11, a combination of Mylar and Dacron, 60 in. wide, costing $.67 a lineal yard. In all cases, the polypropylene was rejected because of adhesive deficiencies, noted either during initial ply adhesion or during flex-testing, and production problems in the lamination. The most promising film was the M-1-MD, a Dacron-Mylar combination whose reinforcing fibers formed a nonwoven grid laid in three directions.

2.2 Design Simplifications

The design was simplified in two ways. First, the balloon valving duct was made rectangular instead of elliptic, thereby allowing machine rather than hand installation; the duct was also reinforced, which eliminated a structural discontinuity in the balloon wall without interfering with the mechanism for valving excess lifting gas at the ceiling altitude of the balloon. Second, modifications in the balloon end fittings (Figure 1) reduced the installation time; the cost of the fittings dropped from \$3,500 to \$500. Changes in the valve wire and inflation tube installations appreciably simplified fabrication and resulted in a better end product as well.

2.3 Production Improvements

A cost analysis of earlier scrim balloons disclosed that fabrication labor accounts for approximately three-quarters of the total cost of a scrim balloon. Two procedures requiring many man hours of labor are gore-cutting and sealing. To determine the actual cost reduction afforded by the design simplifications and procedural changes evolving from our laboratory investigation, we fabricated two balloons.

First, all the gores for the test balloons were cut simultaneously, with a Wolfe cutter. Second, the gore-sealing speed was increased from eight to twenty feet per minute. The acceptability of both changes was supported by numerous preproduction tests. In addition, newly developed equipment for inspecting and splicing balloon material and for automatically dispensing material was used. Seal-tape splices and the use of larger rolls of sealing tape contributed to further reductions in production time. The net result of all of the improvements was a 30 percent reduction in the overall cost of a balloon exactly the same size (1.6 million cubic feet) as one manufactured just one year earlier.

Figure 2 shows the first of the two experimental scrim balloons during perhaps the most critical phase of a dynamic launching. This balloon was launched from the AFCRL R&D Test Facility, Holloman Air Force Base, New Mexico, and carried a payload of 4,000 pounds to an altitude of 74,000 feet. The performance was excellent.

3. RESULTS OF THE COST REDUCTION PROGRAM TO DATE

The curves in Figure 3 illustrate the cost reductions achieved, based on comparative costs of the 3.2 million-cubic-foot balloons first designed and procured for Project Stargazer at a cost of \$54,000 per balloon. The progression is downward to the AFCRL-sponsored, Johns Hopkins University program, and subsequently to the Coronascope and US Weather Bureau programs, at a cost of \$33,000 each. In all of these balloons the scrim material used was the woven one designated GT-12. If the nonwoven GT-50 had been used, a further cost reduction of approximately two thousand dollars could have been expected. The broken line indicates the most pessimistic cost outlook of the next phase in cost reduction: the use of a scrim layer.

4. SCRIM LOOM

Aside from the actual cost reduction, perhaps the most important effect of the work described was the application of nonwoven scrim to balloon design. This opened the way not only to further cost reductions, but to significant improvements. Use of the nonwoven scrim was expedited by Korn's innovation of a simple loom. The first loom model was made inhouse, and a prototype (Figure 4) then manufactured under contract. This machine can best be described as a rotating-drum loom. It dispenses diagonal threads from the large rotating drum and longitudinal threads from a thread beam passing through the center of the drum. Notable advantages are: (1) elimination of the need for the flocking agent (Figure 5) used on nonwoven scrim material for thread stability during handling and shipping; (2) the thread layer permits tailoring threads to conform to the optimum gore reinforcement. For the first time the balloon designer will have an optimum material —one that has uniform longitudinal strength along the gore and can be varied in transverse strength as required.

Figure 6 illustrates three possible variations in thread pattern relative to the balloon gore that is finally cut from the basic scrim balloon fabric. Gores cut from the GT-12 rectangular-thread material lose numerous longitudinal threads. This requires changing the design to enlarge the width of the gores both top and bottom so as to ensure sufficient strength in the end sections. Gores cut from the GT-50 nonwoven thread material also lose many of the longitudinal threads. In the third version shown the longitudinal threads have been so tailored that a large end section is no longer necessary. Another innovation, not illustrated, has to do with spacing the diagonal threads from top to bottom of the gore to conform to the stress distribution in the balloon. The spacing of the longitudinal threads can easily be controlled by selective spacing of the longitudinal feeds. The speeds of the laminator and of the thread-dispensing drum, as well as the number of spools in the drum, can be controlled to produce desired variations in the spacing and angle of the diagonal threads. These features will be incorporated in the thread loom now under construction.

5. BALLOON RECOVERY

The recovery and reuse of scrim balloons are being investigated as a possibility for further cost reduction. The most promising technique features the tandem balloon, whose launching and recovery are respectively illustrated in Figures 7 and 8. Essentially, when the flight terminates the expensive lower balloon is ensleeved in a relatively heavy (2-oz/yd^2) nylon material that fully protects the balloon during the landing and recovery phases of the flight operations.

In our single test to date—carrying a 4,000-pound payload to an altitude of 76,000 feet—the launching, ascent, and flight of the two-balloon system proceeded perfectly (Figure 9). During the descent, however, human error caused premature termination of the flight. No conclusion regarding the recovery technique is therefore presently possible, but our experiments with sleeve drop tests do indicate that balloon recovery is clearly feasible.

Recovery and reuse of scrim balloons on a routine basis will place scrim balloons in direct competition with the heavy-payload polyethylene balloons. Figure 10 illustrates the cost reduction possibilities of the tandem balloon recovery concept. Assuming a flight to 80,000 feet, the recovery and single reuse of a balloon would reduce the cost of the second flight to approximately 60 percent of the cost of the first. In this case, the system would be launched first as a tandem-balloon system and then, following recovery, as a single-balloon system (the top balloon having no essential function on a nonrecoverable system). The recovery and reuse of the main balloon twice (involving two expendable top balloons) would reduce the cost of the third flight to approximately 45 percent of the cost of the first. Projecting this to many reuses would probably lead to unrealistic figures although at some later date our experience might support such projections.

6. SUMMARY

Scrim balloon costs have been reduced 30 percent, with no decrease in the quality of the product.

Nonwoven fibers have been successfully used for balloon reinforcement. In addition to reducing balloon costs, this development opens the way to a whole new technology for the balloon designer.

The scrim loom eliminates the need for using a flocking agent on the scrim material. In the long run, it will allow selection of the proper strength and weight parameters for a more nearly optimum balloon design. Incorporation of the gore-cutting feature will result in still further reduction of balloon costs.

Sleeve-drop tests to date clearly support the feasibility of recovering and reusing scrim balloons.

The dynamic launching of scrim balloons has been amply demonstrated to be feasible and should be used whenever the flight operation permits.

7. FUTURE WORK

The work on balloon shapes is being extended to determine optimum reinforcing scrim patterns. The results will be applied toward improving the nonwoven scrim loom design. The balloon recovery program will extend to testing several newly proposed techniques. The search for materials that are less expensive than Mylar and Dacron will continue. The results of these efforts will be applied as a total technology to the problem of creating a high-altitude medium-payload balloon at the earliest opportunity.

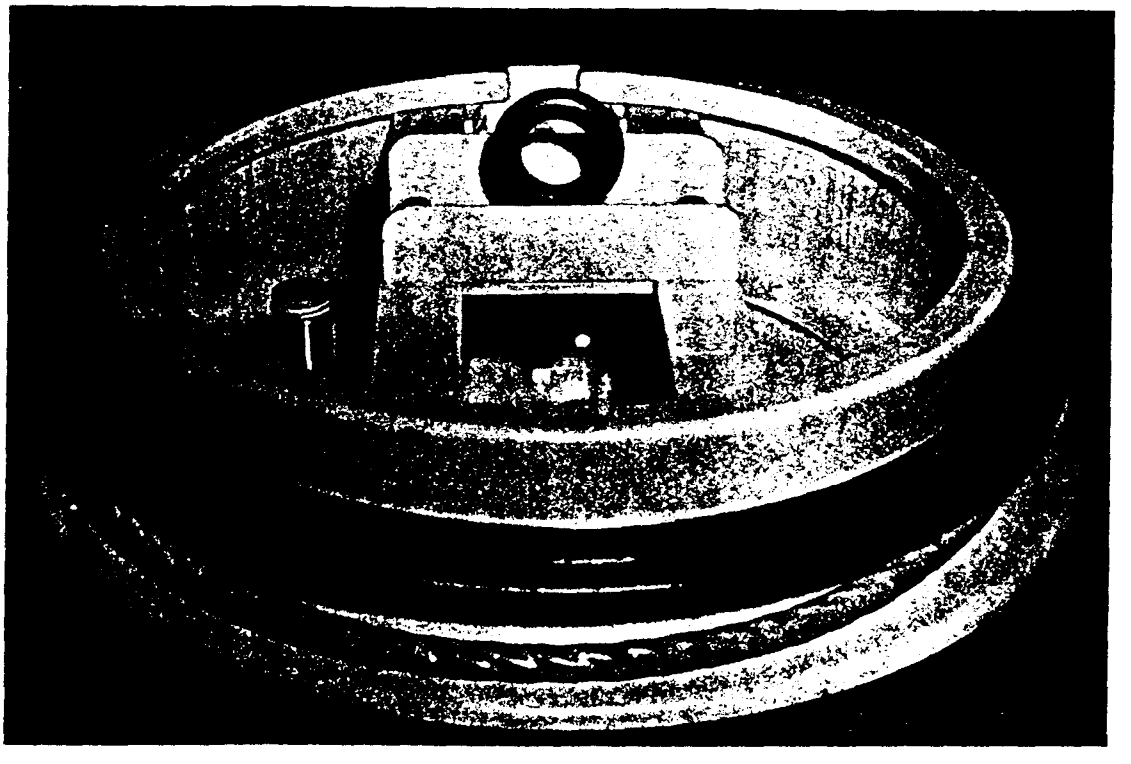

Figure 1. New End-Fitting Design

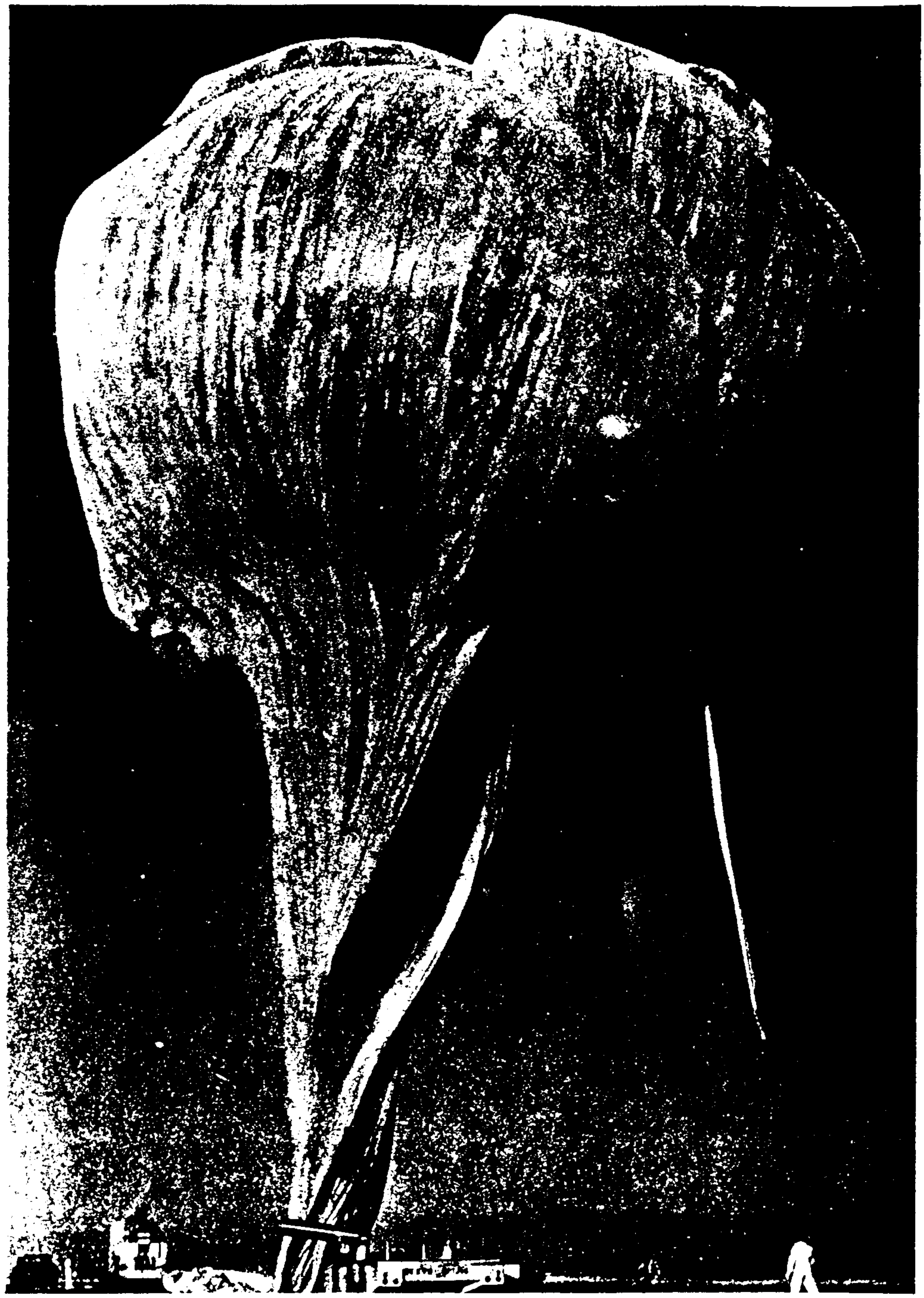

Figure 2. Launch of First Nonwoven Scrim Balloon (24 April 1964)

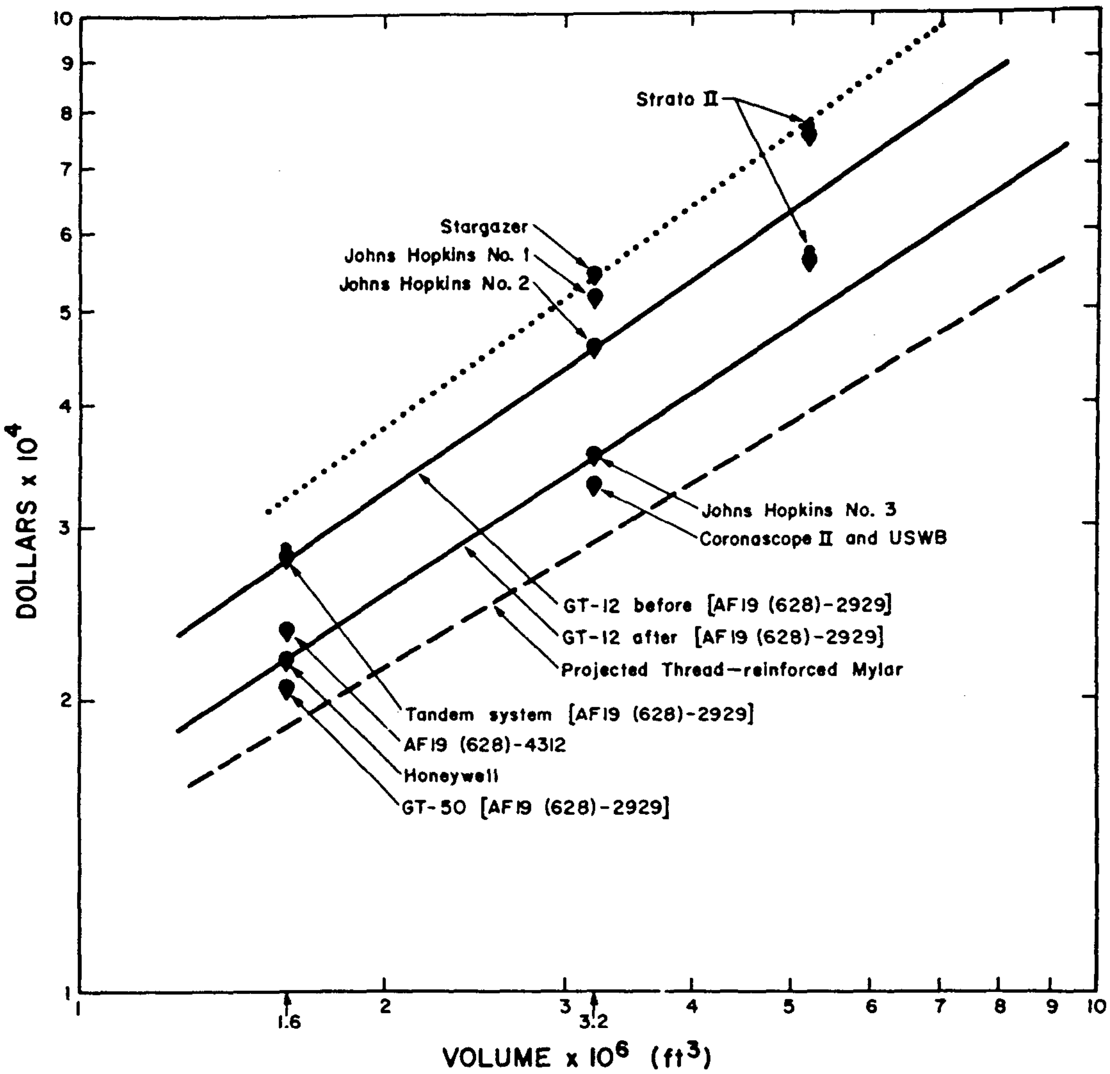

Figure 3. Comparative Costs of Heavy-Load Balloons

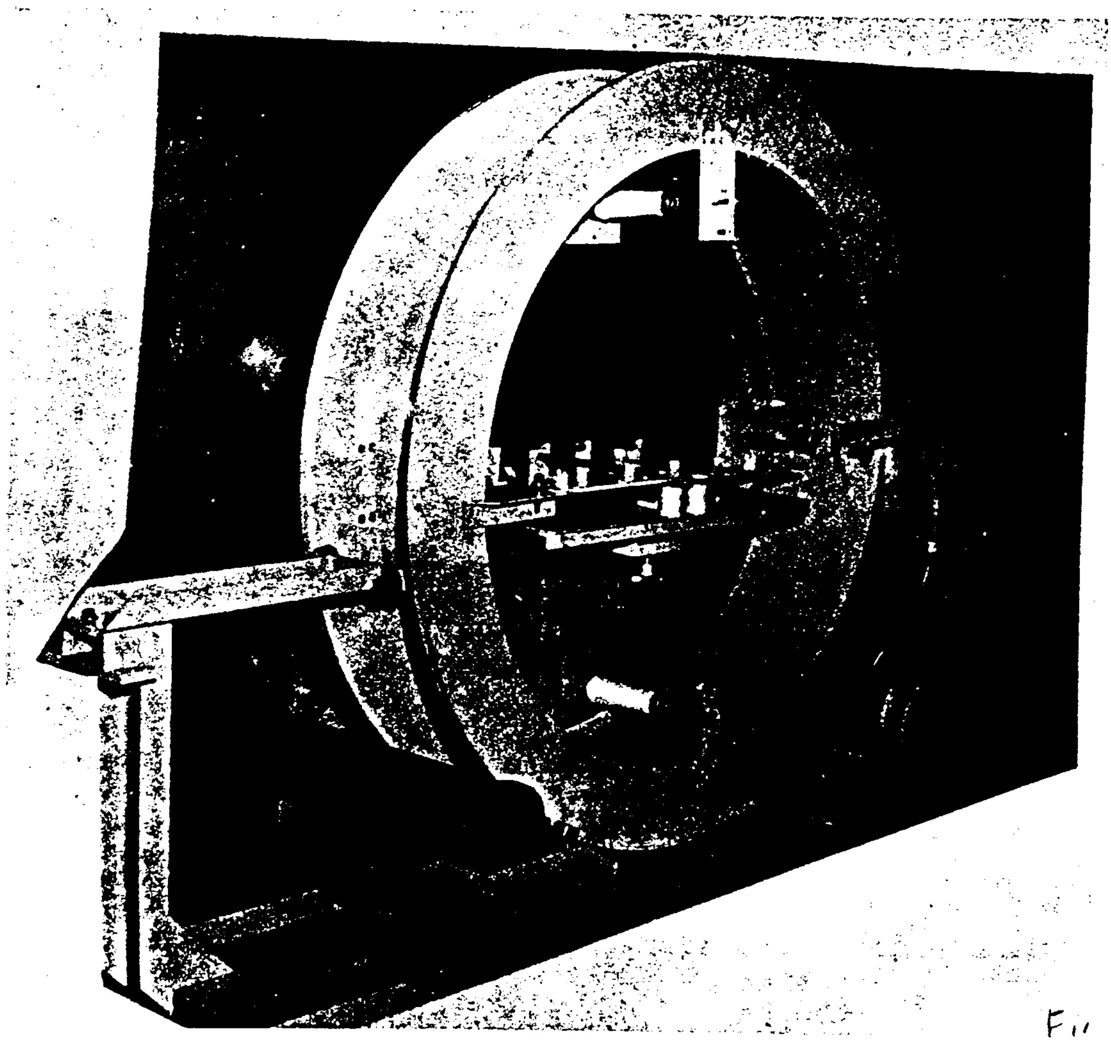

Figure 4. Model for Nonwoven Scrim-Layer

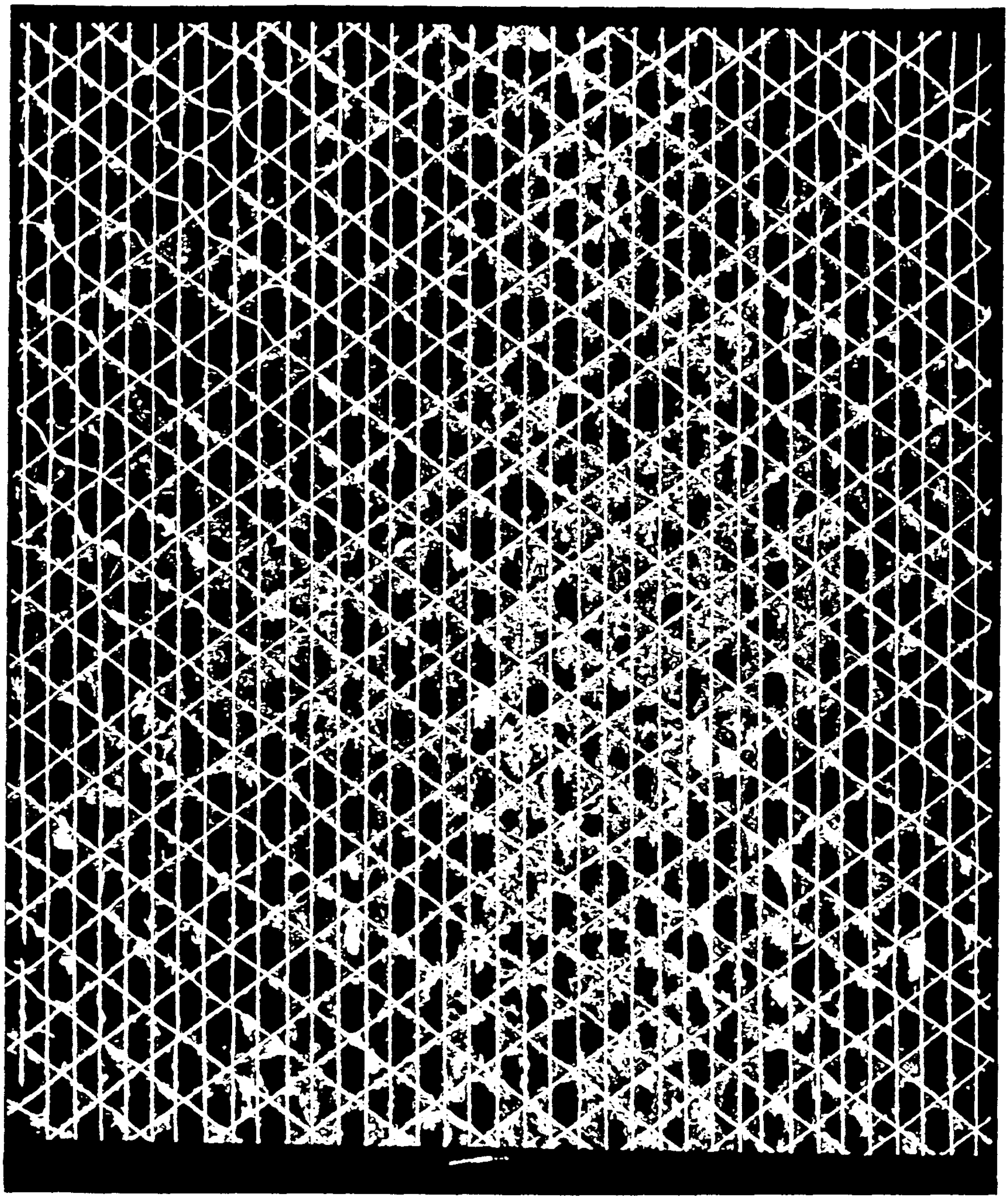

Figure 5. Toscony Nonwoven Scrim

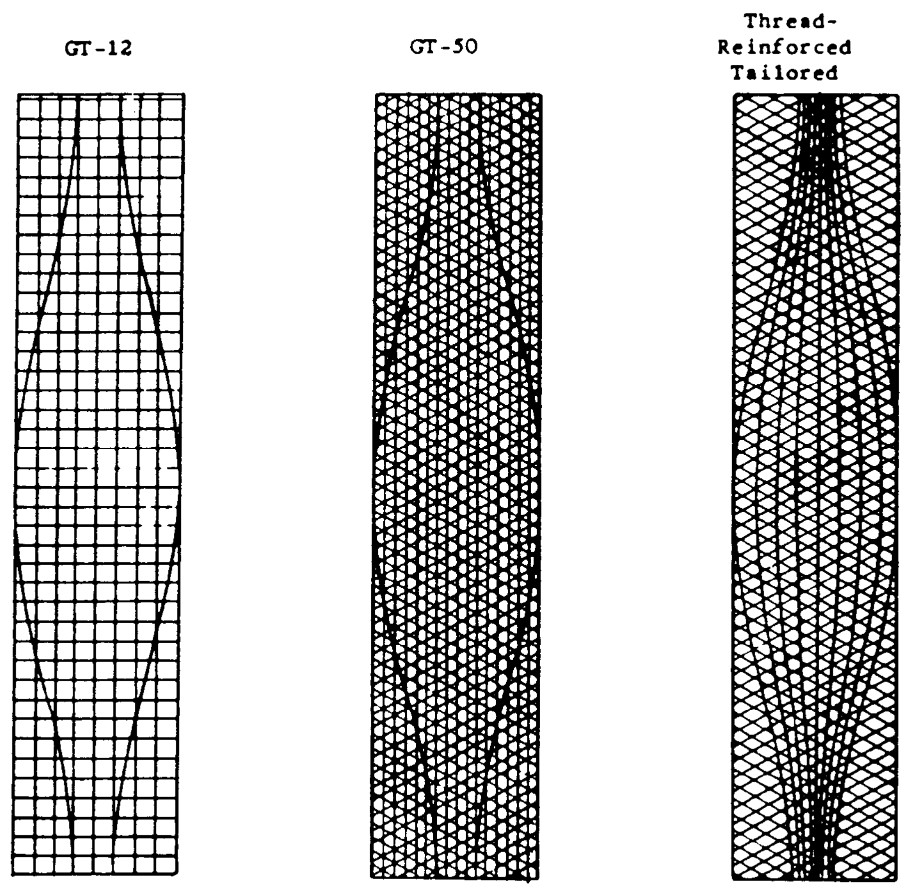

Figure 6. Gore Reinforcement Patterns

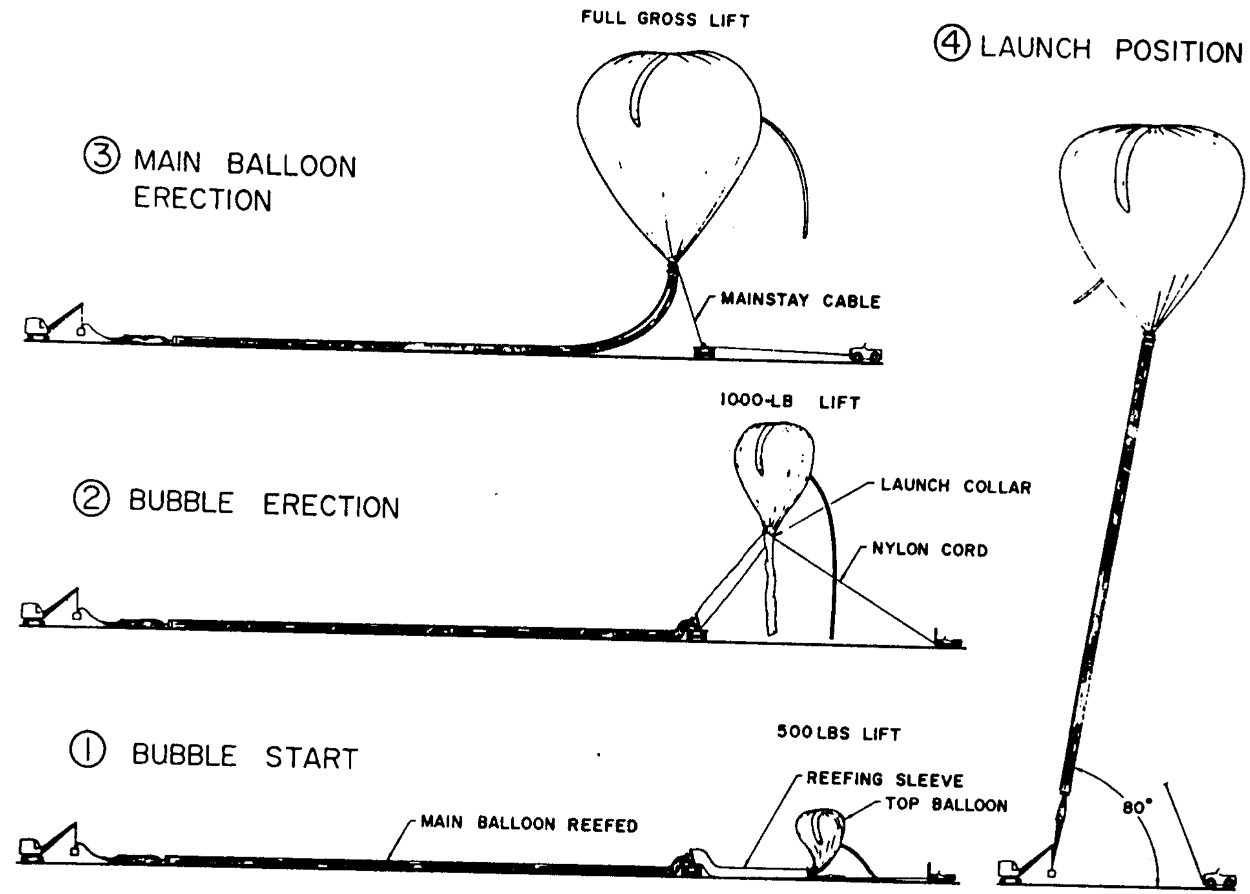

Figure 7. Launch Sequence 1.6 Tandem System [AF19(628)-2929]

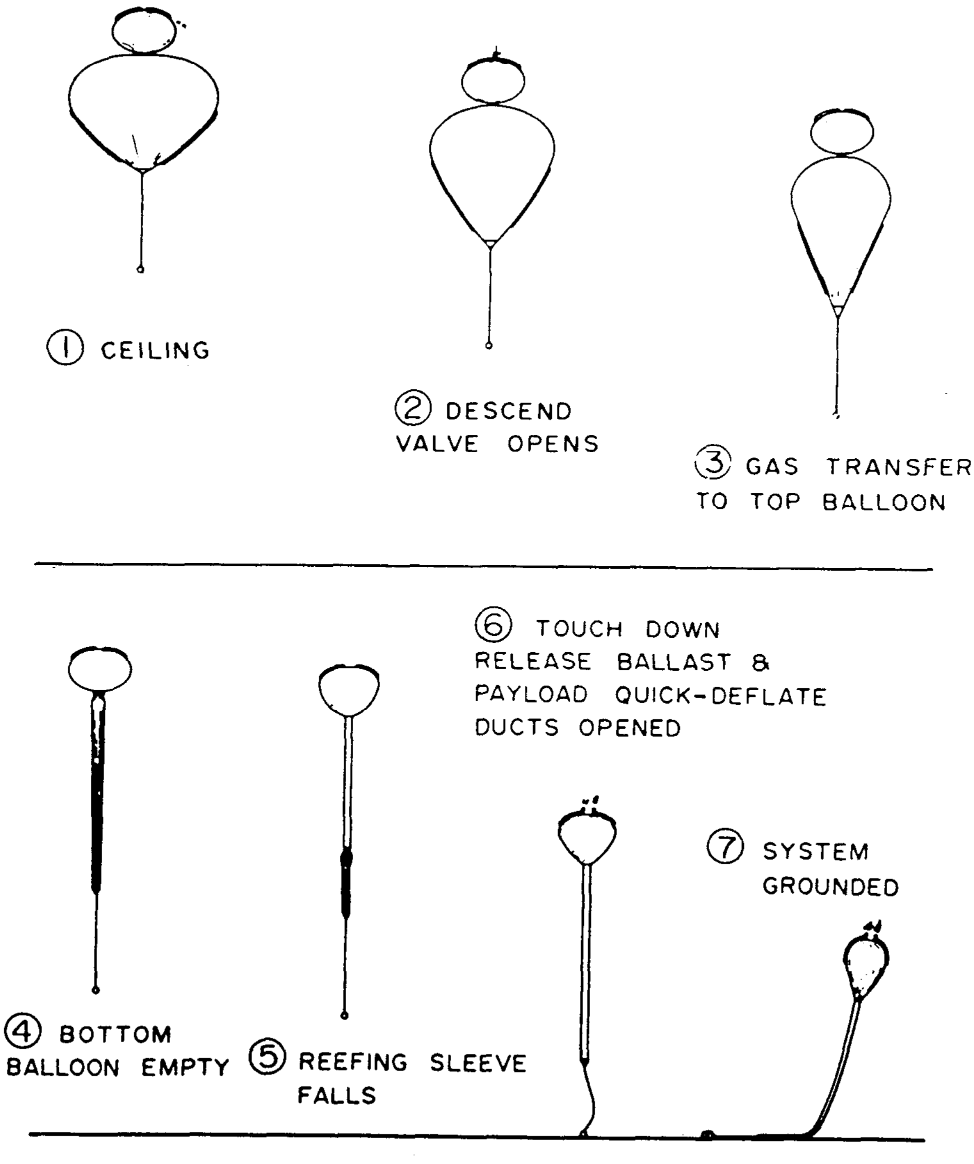

Figure 8. Tandem Balloon Recovery [AF19(628)-2929]

Figure 9. Tandem Balloon Reel-Up

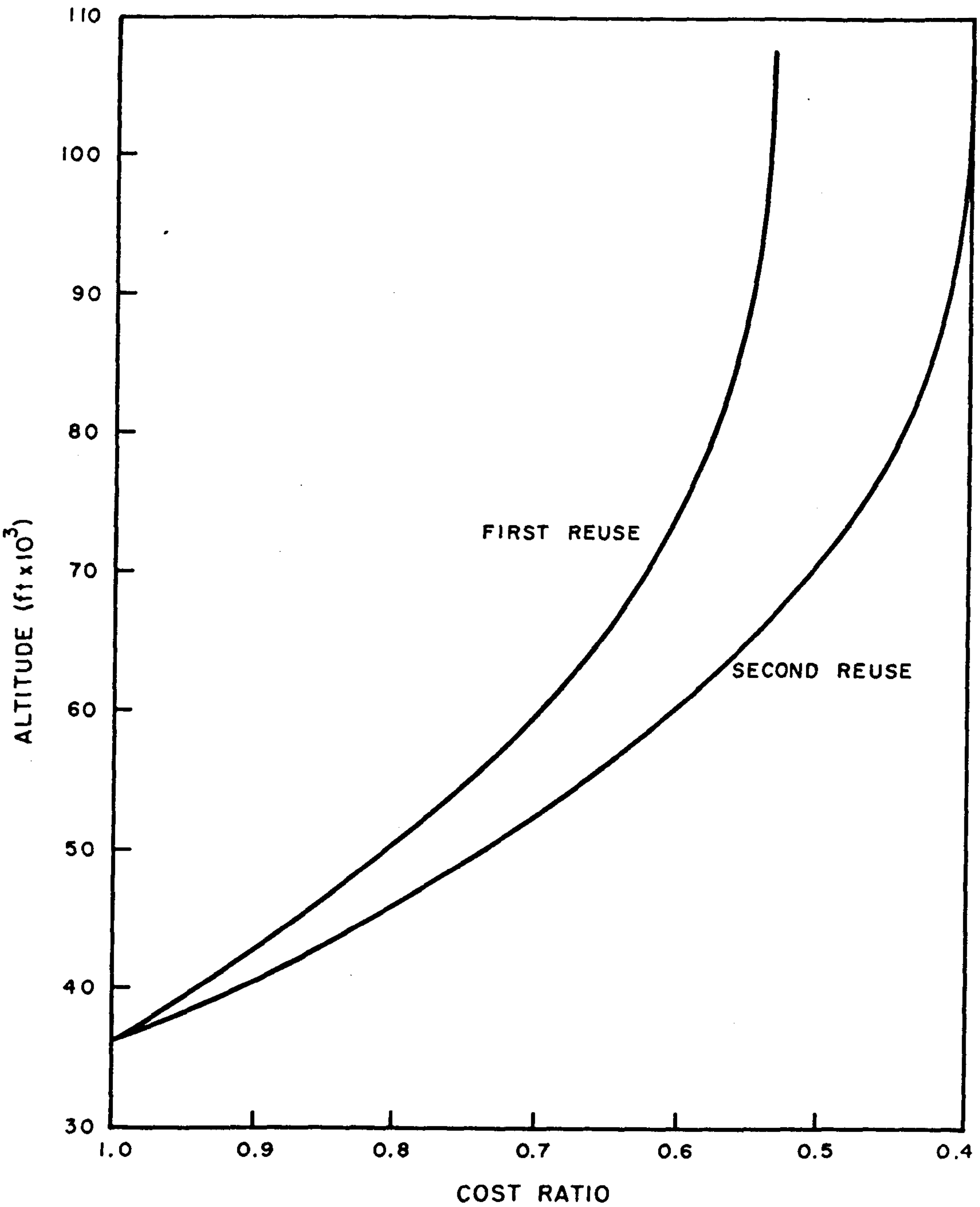

Figure 10. Flight Costs [assumes 100% recovery of main balloon (GT-11)]

Table 1. Characteristics of Reinforcing Materials

Material	Dacron*	Rayon	Polypropylene	Dacron, nonwoven
Weave	leno	leno	leno	three-ply, nonwoven
Weight (oz/yd^2)	0.6	1.58	0.6	0.6
Width	60 in.	60 in.	60 in.	56 in.
Thread count	12 x 4	14 x 5	12 x 5	5 x 3 x 3
Yarns (denier)				
warp	220	300	210	220 high-tenacity
fill	2-ply	600	420	220 rotoset
Tensile strength (ppi)				
warp direction	25	27.7	30	25
fill direction	16	26.4	27	15 (diagonal)
Price/running yard (for less than 100,000 yd 60 in. wide)	$0.2475	$0.175	$0.1875	$0.165

*Scrim now used in GT-11 balloon material

Table 2. Characteristics of Selected Gas-Barrier Film Materials

Designation		Maximum Width (in.)	Price per Pound	1-mil Film, Yield per Pound (in^2)	0.5-mil Price/Yd^2	Approximate Tensile Strength (psi)	Notes
Mylar	Type C (50 ga)	84	$ 2.50	20,000	0.075	20,000	standard material
polypropylene	Moplefane (50 ga)	36	0.84	31,000	0.018	15,000	adhesive problem
polypropylene	Udel (45 ga)	60	1.65	31,000	0.030	25,000	available also 0.6 mil
polypropylene	Hercules B-103 (50 ga)	72	1.40	31,000	0.031	30,000	corona-treated both sides
nylon	Capran 77C (50 ga)	40	2.50	24,000	0.070	7,000	dielectric-sealing possibility; high elongation

Table 3. Evaluation of Sample Laminates

Code	GT-11	P-1-D	M-1-P	P-1-P	M-1-MD
Film	1/3-mil Mylar	1/2-mil polypropylene	1/3-mil Mylar	1/2-mil polypropylene	1/3-mil Mylar
Reinforcement	Dacron	Dacron	polypropylene	polypropylene	nonwoven Dacron 5 x 3 x 3
Weight (gm/yd^2)	36.2	35.3	37.8	33.8	34.5
Warp tensile strength (ppi), & % elongation at room temperature	38.8, 12%	41.5, 14%	35, 56%	42, 67%	26, 11%
Warp tensile strength (ppi), & % elongation at -80°F	51.4, 13%	63.7, 14%	45, 33%	57, 35%	33, 9%
Fill tensile strength (ppi), & % elongation at -80°F	42.5, 16%	35.6, 13%	40, 40%	45, 42%	diagonal 20, 9%
Ply adhesion (ppi) at -80°F	1.3	0.7	0.15	0.03	film tore; no de-lamination
Seal tensile strength (ppi) at -80°F	43.6	36.0	26	29	11 (diagonal 20)
Flex test	OK	OK	Fail (7)	Fail (8)	OK
Material cost per lineal yd	$.67	$.59	$.60	$.52	$.56